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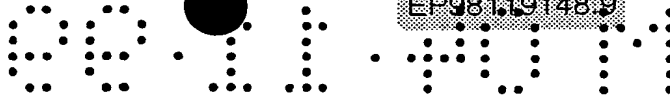
Mitsubishi Semiconductor  
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## MULTIPLEXER CIRCUIT AND ANALOGUE-TO-DIGITAL CONVERTER

The invention relates to a multiplexer circuit according to the preamble of claim 1 and to an analogue-to-digital converter (ADC) comprising such a multiplexer circuit.

In monolithic IC's transmission gates can be used for multiplexer circuits. They are suitable to select one of several analogue input channels to connect the selected channel, for example, to an ADC circuit on chip. Multiplexer circuits built with transmission gates implemented in monolithic IC's with MOS (metal oxide semiconductor) type circuits are known from CMOS Digital Integrated Circuits, Analysis and Design, S.M. Kang, Y. Leblebici, MCGRAW-HILL INTERNATIONAL EDITIONS, ISBN 0-07-038046-5, page 274 and from Principles of CMOS VLSI Design, A System Perspective, second edition ADDISON WESLEY, N.H.E., Weste, K. Eshraghian, ISBN 0-201-53376-6, pages 17, 304.

An example of a conventional multiplexer circuit 1 comprising transmission gates is shown in Fig. 4. The multiplexer circuit 1 comprises at least two input channels  $IN_0$ ,  $IN_1$  which are connected with a common output channel 2. Of course, a plurality of input channels  $IN_0$ ,  $IN_1$ ,  $IN_2$ , ...  $IN_i$  may be provided in the multiplexer circuit. For selecting one of said analogue input channels  $IN_0$ ,  $IN_1$  the multiplexer circuit comprises transmission gates  $FT_0$ ,  $FT_1$  between the input channel  $IN_0$ ,  $IN_1$  and the output channel 2, respectively. The multiplexer can select one of the two input channels  $IN_0$ ,  $IN_1$  by select signals  $SELECT_0$ ,  $\overline{SELECT_0}$ ,  $SELECT_1$ ,  $\overline{SELECT_1}$  generated by a decoder circuit 10. The decoder circuit generates a select signal  $SELECT_0$ ,  $SELECT_1$  and an inverted select signal  $\overline{SELECT_0}$ ,  $\overline{SELECT_1}$  for each input channel  $IN_0$ ,  $IN_1$ , respectively, which are



applied to the corresponding transmission gates  $FT_0$ ,  $FT_1$ . The decoder circuit is a  $n$  to  $2^n$  decoder ( $i = 2^n$ ), which ensures that only one of the select signals  $SELECT_0$  to  $SELECT_i$  becomes true while the others are false, i.e. only one channel is open while the others are closed. In the example according to Fig. 4 the channel  $IN_1$  is selected i. e. the transmission gate  $FT_1$  is open, whereas the channel  $IN_0$  is not selected and the transmission gate  $FT_0$  is closed. Analog voltages  $U_1$ ,  $U_2$  are applied to the input channels  $IN_0$ ,  $IN_1$ , respectively. The voltage at the output channel 2 is indicated as  $U_{out}$ . The transmission gates  $FT_0$ ,  $FT_1$  are known CMOS transmission gates comprising p channel and n channel transistors having threshold voltages  $V_{THp}$  and  $V_{THn}$ , respectively. The multiplexer circuit is operated with a power supply voltage  $V_{cc}$  and  $V_{ss}$  is the ground potential 0V.

The operation of the multiplexer circuit is as follows. In a normal operation condition the following input voltage conditions are applied:

$$\begin{aligned} U_1 &= [V_{ss}; V_{cc}] \\ U_2 &= [V_{ss}; V_{cc}]. \end{aligned}$$

That means the level of the input voltages  $U_1$ ,  $U_2$  is between the power supply voltage level  $V_{cc}$  and  $V_{ss}$ .

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Under these conditions the transmission gates  $FT_0$  and  $FT_1$  operate as ideal switches. Since the transmission gate  $FT_0$  is closed, the voltage  $U_{out}$  is equal to  $U_2$ :

$$U_{out} = U_2.$$

No current will flow in the multiplexer circuit, i.e. the current in the channels  $IN_0$  and  $IN_1$  is 0, respectively:

$$\begin{aligned} I_{in1} &= 0 \\ I_{out} &= 0. \end{aligned}$$

In case of an over or an under voltage applied to an input channel which is not selected i. e. which is not active a current will flow through the active channel. This is the under/over voltage operation condition. The following input voltage conditions are considered as under and over voltage conditions:

Under voltage:

$$-V_{THn} + V_{SS} \leq U_1 \leq V_{SS}.$$

Over voltage:

$$V_{CC} \leq U_1 \leq V_{CC} + |V_{THp}|,$$

The voltage  $U_2$  is:

$$U_2 = [V_{SS}; V_{CC}].$$

Under these conditions the transmission gate  $FT_0$  in channel  $IN_0$  does not work as an ideal switch any more. Due to "weak inversion" and the pn-diode structures of the CMOS transistors a current flows between  $IN_0$  and  $IN_1$ .

$$|I_{in}| \geq 0$$

$$|I_{out}| \geq 0$$

$I_{out}$  creates a voltage drop at the resistance of the transmission gate  $FT_1$  in channel  $IN_1$  and the output resistance of the source of  $U_2$ . Therefore,  $U_{out}$  is not equal to the input voltage  $U_2$  any more. Depending on the desired accuracy of the analogue signal this will be a problem.

In particular for multiplexer circuits used in ADC's a noise at the injection source leads to worse accuracy, which makes the conversion results unusable (e.g. in case of an 8-bit ADC the absolute accuracy becomes 10-11 LSB instead of  $\pm 2$  LSB).



External over/under voltage protection circuits are required in order to be able to use such ADC's.

It is an object of the invention to provide a multiplexer circuit and an analogue-to-digital converter having an improved accuracy with respect to the output of an analogue input signal.

The object is solved by a multiplexer circuit according to claim 1 and by an analogue-to-digital converter according to claim 12. Further developments of the invention are described in the dependent claims.

Embodiments of the invention will be explained with reference to the accompanying drawings.

Fig. 1 shows a multiplexer circuit according to a first embodiment of the invention.

Fig. 2 shows a multiplexer circuit according to a second embodiment of the invention.

Fig. 3 shows a multiplexer circuit according to the second embodiment of the invention more in detail.

Fig. 4 shows an example of a conventional multiplexer circuit.

A first embodiment of the multiplexer circuit according to the invention is shown in Fig. 1. Parts which are the same as in the conventional multiplexer circuit according to Fig. 4 are designated with the same reference signs and the description thereof will not be repeated.

The multiplexer circuit according to this embodiment comprises a first transmission gate  $FT_0$ ,  $FT_1$ , for each channel respectively, and a second transmission gate  $ST_0$ ,  $ST_1$  for each channel. The output of the first transmission gate  $FT_0$ ,  $FT_1$  in each channel is connected with the input of the second

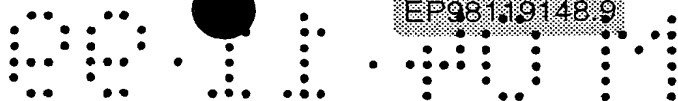


transmission gates  $ST_0$ ,  $ST_1$ , respectively. The output of the second transmission gate  $ST_0$  and  $ST_1$  is connected with the output channel 2. The second transmission gate  $ST_0$ ,  $ST_1$  are controlled by the same select signals  $SELECT_0$ ,  $\overline{SELECT_0}$  and  $SELECT_1$ ,  $\overline{SELECT_1}$  as the first transmission gates  $FT_0$ ,  $FT_1$ .

A bypass circuit in form of an NMOS transistor 20, 21 is provided for each analogue input channel  $IN_0$ ,  $IN_1$ . Each NMOS transistor 20, 21 is connected with its drain to a node 30 31. Each node 30, 31 is connected with the output of the first transmission gate  $FT_0$ ,  $FT_1$  and the input of the second transmission gate  $ST_0$ ,  $ST_1$ , respectively. The source of each NMOS transistor 20, 21 is connected with the ground potential level  $V_{ss}$ . The gate of each NMOS transistor receives the inverted select signal  $\overline{SELECT_0}$ ,  $\overline{SELECT_1}$ , respectively, which is generated by the channel decoder 10. In this embodiment the NMOS transistors are controlled by the same select signal as the PMOS transistor of the transmission gates.

In the example according to Fig. 1 the channel  $IN_1$  is selected and the first transmission gate  $FT_1$  and the second transmission gate  $ST_1$  are both open. Since the NMOS transistor 21 receives the inverted select signal  $\overline{SELECT_1}$  on its gate, the NMOS transistor 21 is switched off for the selected channel  $IN_1$ . The channel  $IN_0$  is not selected and therefore, the first transmission gate  $FT_0$  and the second transmission gate  $ST_0$  are both closed. Since the NMOS transistor 20 receives the inverted select signal  $\overline{SELECT_0}$  on its gate, the NMOS transistor 20 is switched on for the not selected channel  $IN_0$ .

In operation the select signals are applied to the transmission gates such that the input channel  $IN_1$  is selected by opening the first transmission gate  $FT_1$  and the second transmission gate  $ST_1$  by the select signal  $SELECT_1$  ( $SELECT_1 = 1$ ). The other input channel  $IN_0$  is not selected by closing the first transmission gate  $FT_0$  and the second transmission gate  $ST_0$  by applying the select signal  $SELECT_0$  ( $SELECT_0 = 0$ ).



In case the voltage  $U_1$  applied to the first input channel  $IN_0$  has an over voltage i.e.

$$V_{CC} \leq U_1 \leq V_{CC} + |V_{THp}|,$$

a current  $I_{in1}$  flows through the first transmission gate  $FT_0$  to node 30. Since the NMOS transistor 20 is switched on by the select signal  $\overline{SELECT}_0$ , the current  $I_{in1}$  is bypassed through the NMOS transistor 20 to ground. The potential at node 30 is (due to being pulled down by NMOS transistor 20) in the range of  $[0, V_{CC}]$ . Therefore, the transmission gate  $ST_0$  operates as an ideal switch, i.e. closes perfectly. Therefore, the selected input channel  $IN_1$  is not influenced by the under voltage on the first input channel  $IN_0$ . The output voltage  $U_{out}$  is equal to  $U_2$ .

Without changing the circuit in Fig. 1 the NMOS transistor 20 pulls an undervoltage  $-V_{TH,N} < U_1 < 0$  at the input to a potential in the range of  $[-V_{TH,N}, 0]$  at node 30. This is enough to switch the transmission gate  $ST_1$  off and to avoid influence to the analogue input. Hence, the NMOS transistor is a measure against undervoltage, too. However, the bypass behaviour of the NMOS transistor for overvoltage condition is better than for undervoltage condition.

Fig. 2 shows an embodiment of a multiplexer circuit in order to ~~bypass the current for over or under voltage conditions~~. In the embodiment according to Fig. 2 parts which are equal to parts of the embodiment according to Fig. 1 are described with the same reference signs. The multiplexer circuit according to Fig. 2 comprises a pull-down bypass circuit 50, 51 in each channel  $IN_0$ ,  $IN_1$  and in addition a pull-up bypass circuit 60, 61. The pull-down bypass circuit 50, 51 is connected between a node 70, 71 and  $V_{SS}$  level and the pull-up bypass circuit 60, 61 is connected between the node 70, 71 and  $V_{CC}$  level, respectively.

The multiplexer circuit according to Fig. 2 also comprises two operation conditions: In the normal operation condition the following input voltage conditions are applied:

$$U_1 = [V_{SS}; V_{CC}]$$

$$U_2 = [V_{SS}; V_{CC}].$$

Under these conditions the transmission gates operate as ideal switches. The voltage  $U_{out}$  is equal to  $U_2$ . No current will flow:

$$I_{in} = 0$$

$$I_{out} = 0.$$

In an under/over voltage operation condition the following input voltage conditions are considered as under and over voltage conditions:

Under voltage:

$$-V_{THn} + V_{SS} \leq U_1 \leq V_{SS}$$

Over voltage:

$$V_{CC} \leq U_1 \leq V_{CC} + |V_{THp}|$$

( $V_{THn}$ ,  $V_{THp}$  are threshold voltages of p- and n channel transistors)

The voltage  $U_2$  is:

$$U_2 = [V_{SS}; V_{CC}].$$

Under these conditions the first transmission gate  $FT_0$  in channel  $IN_i$  does not work as an ideal switch. The current  $I_{in1}$  is bypassed to  $V_{SS}$  level or  $V_{CC}$  level by using the bypass circuit 50 or 60. The second transmission gate  $ST_0$  is implemented in order not to change the  $U_{out}$  voltage. In case of an over/under voltage condition the bypass circuit 50 reduces the input voltage for the second transmission gate  $ST_0$ , so that

no over voltage condition occurs at the second transmission gate  $ST_0$  and the bypass circuit 60 increases the input voltage for the second transmission gate, so that no under voltage condition occurs at the second transmission gate  $ST_0$ . Therefore, the second transmission gate will work again as an ideal switch. As a result no current flows between  $IN_0$  and  $IN_1$  and the voltage  $U_{out}$  is equal to the input voltage  $U_2$ , i.e.

$$\begin{aligned} |I_{in1}| &\geq 0 \\ |I_{in2}| &= 0 \\ |I_{out}| &= 0 \\ U_{out} &= U_2. \end{aligned}$$

Fig. 3 shows a specific embodiment of the multiplexer circuit according to Fig. 2. For each channel the pull-down bypass circuit 50 is realized with an NMOS transistor 80, 81 and the pull-up bypass circuit is realized with a PMOS transistor 90, 91, respectively. The NMOS transistor will be used as over voltage protection and the PMOS transistor will be used as under voltage protection on channels that are not selected.

A control circuit for the bypass circuits comprises NOR gates 100, 101, the output of which is connected with the gate of the NMOS transistor 80, 81, respectively. The control circuit further comprises NAND gates 110, 111, the output of which is connected with the gate of the PMOS transistor 90, 91, respectively. ~~One input of the NOR gate 100, 101 is connected~~ with the input voltage  $U_1$ ,  $U_2$ , respectively, and the other input of the NOR gate 100, 101 is connected with the select signal  $SELECT_0$ ,  $SELECT_1$ . One input of the NAND gate 110, 111 is connected with the input voltage  $U_1$ ,  $U_2$ , respectively., and the other input of the NAND gate 110, 111 is connected with the inverted select signal  $\overline{SELECT_0}$ ,  $\overline{SELECT_1}$ . Therefore, the input signals of the control circuit are the input voltage  $U_1$ ,  $U_2$  and the select and the inverted select signals which control the transmission gates. If a channel is not selected ( $SELECT = 0$ ) and an under voltage condition occurs ( $U_1 < 0$  V) the PMOS transistor 90 will be switched on. If a channel is not selected

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(SELECT = 0) and an over voltage condition occurs ( $U_1 > 5 \text{ V}$ ), the NMOS transistor 80 will be switched on.

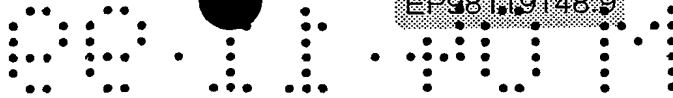
Of course, each of the embodiments according to Figs. 1 to 3 may comprise not only two but a plurality of input channels and each channel may have the pull-up and/or pull-down circuits and the second transmission gates as described above.

An ADC circuit according to the invention comprises a multiplexer circuit according to the embodiments of Figs. 1 to 3 where the output voltage  $U_{out}$  of the multiplexer is the input voltage for the ADC. The accuracy of such an ADC can be as good as without over/undervoltage, i.e. the over/undervoltage has no influence to the conversion result (e.g. in case of an 8-bit ADC the accuracy is  $\pm 2 \text{ LSB}$  with or without over/undervoltage).

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1. Multiplexer circuit comprising at least two input channels ( $IN_0$ ,  $IN_1$ ) and an output channel (2), each input channel ( $IN_0$ ,  $IN_1$ ) comprising a first transmission gate ( $FT_0$ ,  $FT_1$ ) which can be switched on by a select signal ( $SELECT_0$ ,  $\overline{SELECT_0}$ ;  $SELECT_1$ ,  $\overline{SELECT_1}$ ) for connecting the input channel ( $IN_0$ ,  $IN_1$ ) to the output channel (2), characterized in that at least one of the input channels ( $IN_0$ ,  $IN_1$ ) comprises a bypass circuit (20, 21; 50, 51; 60, 61; 80, 81; 90, 91) for preventing a current flowing through the first transmission gate ( $FT_0$ ,  $FT_1$ ) from reaching the other input channel, and a second transmission gate ( $ST_0$ ,  $ST_1$ ).
2. Multiplexer circuit according to claim 1, wherein each input channel ( $IN_0$ ,  $IN_1$ ) comprises a bypass circuit (20, 21; 50, 51; 60, 61; 80, 81; 90, 91) and a second transmission gate ( $ST_0$ ,  $ST_1$ ).
3. Multiplexer circuit according to claim 2, wherein the bypass circuit (20, 21; 50, 51; 60, 61) is switched on for an input channel ( $IN_0$ ) which is not selected and is switched off for a selected input channel ( $IN_1$ ).
4. Multiplexer circuit according to one of claims 1 to 3, wherein said bypass circuit comprises a pull-down circuit (20, 21; 50, 51; 80, 81) reducing an input voltage for the second transmission gate ( $ST_0$ ,  $ST_1$ ).
5. Multiplexer circuit according to one of claims 1 to 4, wherein said bypass circuit (20, 21) is controlled by said select signal ( $SELECT_0$ ,  $\overline{SELECT_1}$ ).
6. Multiplexer circuit according to one of claims 1 to 5, wherein said bypass circuit (20, 21; 50, 51) is an NMOS tran-



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sistor the gate of which is controlled by said select signal ( $\overline{\text{SELECT}}_0$ ,  $\overline{\text{SELECT}}_1$ ), the drain of which is connected with an output of said first transmission gate ( $\text{FT}_0$ ,  $\text{FT}_1$ ) and the source of which is connected with ground potential ( $V_{ss}$ ).

7. Multiplexer circuit according to one of claims 1 to 6, wherein said bypass circuit comprises a pull-up circuit (60, 61) increasing an input voltage for said second transmission gate ( $\text{ST}_0$ ,  $\text{ST}_1$ ).

8. Multiplexer circuit according to claim 7, wherein said pull-up circuit (60, 61) is a PMOS transistor the drain of which is connected with an output of said first transmission gate ( $\text{FT}_0$ ,  $\text{FT}_1$ ) and the source of which is connected with a power supply voltage level ( $V_{cc}$ ).

9. Multiplexer circuit according to claims 7 or 8, further comprising a control circuit for controlling said pull-up circuit (60, 61) and said pull-down circuit (50, 51) by means of said select signal ( $\overline{\text{SELECT}}_0$ ,  $\overline{\text{SELECT}}_0$ ;  $\overline{\text{SELECT}}_1$ ,  $\overline{\text{SELECT}}_1$ ) and an input voltage ( $U_1$ ,  $U_2$ ) applied to said input channel ( $\text{IN}_0$ ,  $\text{IN}_1$ ).

10. Multiplexer circuit according to claim 9, wherein said control circuit comprises a NAND gate the output of which is connected with the gate of said PMOS transistor and a NOR gate the output of which is connected with the gate of said NMOS transistor.

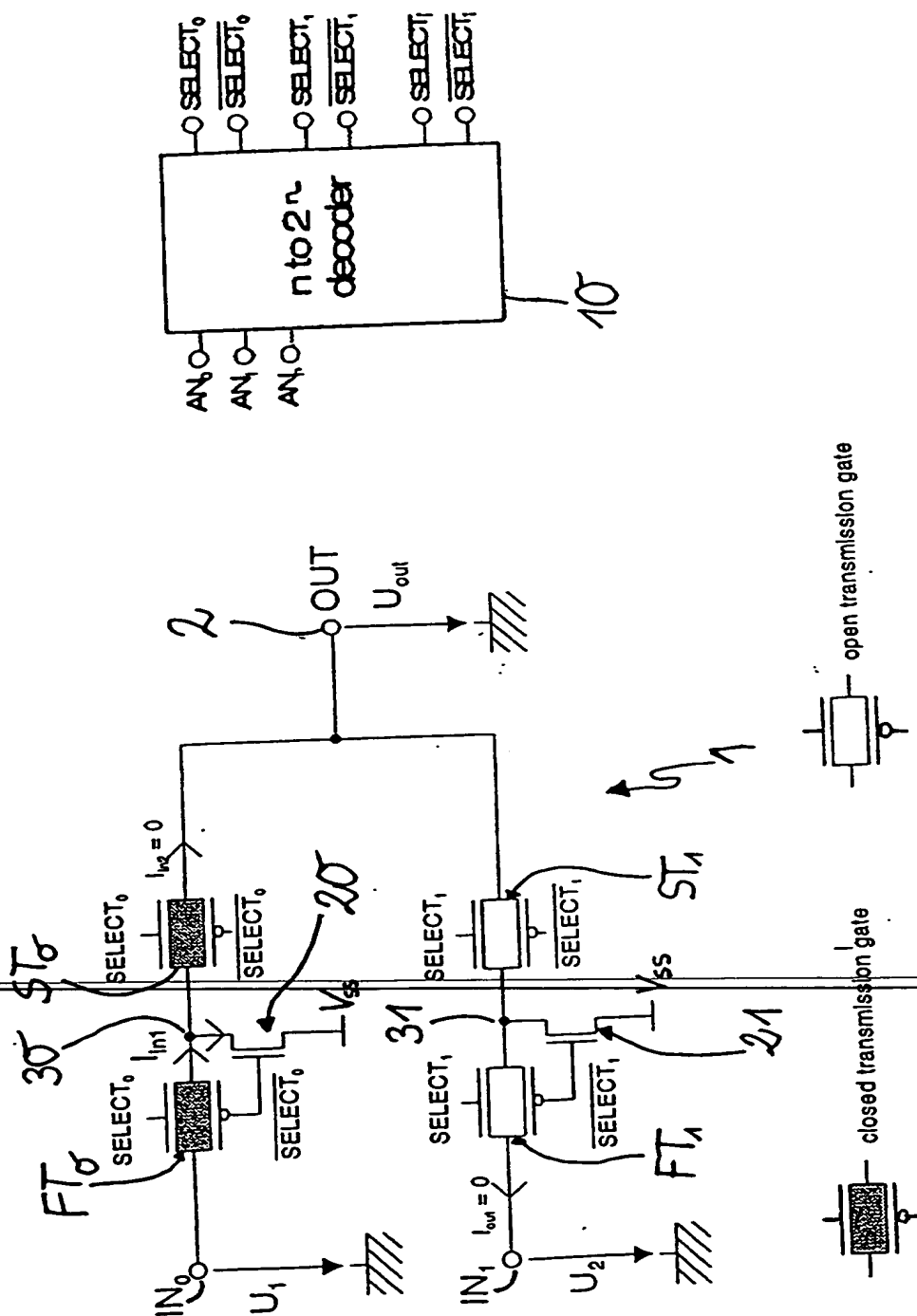
11. Multiplexer circuit according to claim 9, wherein said NAND gate receives the input voltage and the inverted select signal ( $\overline{\text{SELECT}}_0$ ,  $\overline{\text{SELECT}}_1$ ) and said NOR gate receives the input voltage and the select signal ( $\text{SELECT}_0$ ,  $\text{SELECT}_1$ ).

12. Analogue-to-digital converter comprising a multiplexer circuit according to one of claims 1 to 11.



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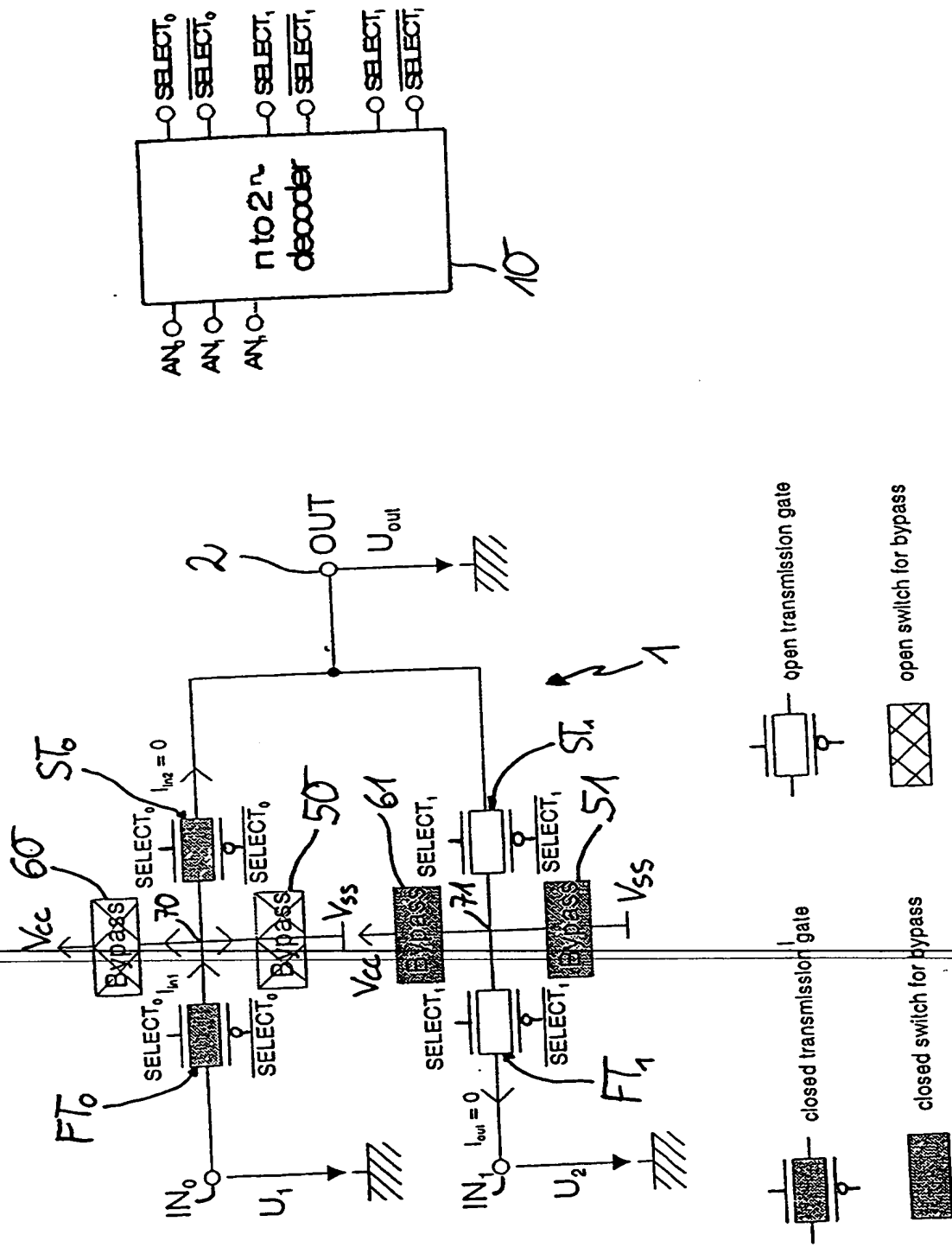


Fig. 2



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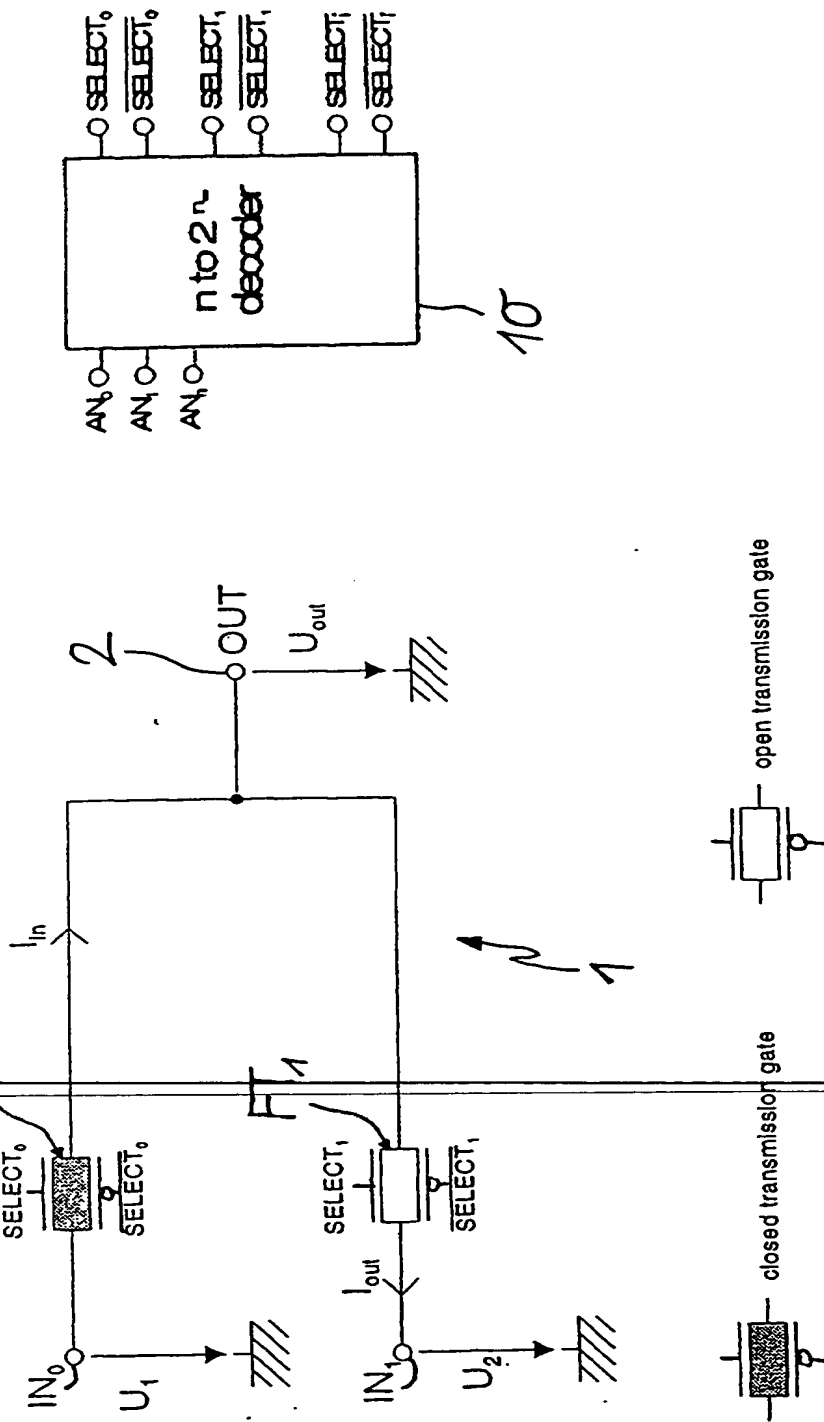


Fig. 4

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## ABSTRACT

A multiplexer circuit (100) comprises at least two input channels ( $IN_0$ ,  $IN_1$ ) and an output channel (2), each input channel ( $IN_0$ ,  $IN_1$ ) comprising a first transmission gate ( $FT_0$ ,  $FT_1$ ) which can be switched by a select signal ( $SELECT_0$ ,  $\overline{SELECT_0}$ ;  $SELECT_1$ ,  $\overline{SELECT_1}$ ) for connecting the input channel ( $IN_0$ ,  $IN_1$ ) to the output channel (2) and wherein at least one of the input channels ( $IN_0$ ,  $IN_1$ ) comprises a bypass circuit for preventing a current flowing through the first transmission gate ( $FT_0$ ,  $FT_1$ ) from reaching the other input channel, and a second transmission gate ( $ST_0$ ,  $ST_1$ ).

(Fig. 2)

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